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SEARCH FOR ELECTROWEAK PRODUCTION OF SINGLE TOP QUARKS AT DØ

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This paper discusses a search for electroweak production of single top quarks in the electron+jets and muon+jets decay channels. The measurements use ≈ 90 pb^{-1} of data from Run 1 of the Fermilab Tevatron collider, collected at 1.8 TeV with the DØ detector. We use events that include a tagging muon, implying the presence of a b jet, to set an upper limit at the 95% confidence level on the cross section for the s-channel process $p\bar{p} \rightarrow tb + X$ of 39 pb. The upper limit for the t-channel process $p\bar{p} \rightarrow tqb + X$ is 58 pb.

The DØ collaboration recently completed a search for single top quarks produced in association with a bottom quark or with a light quark and a low-p_T b quark.[1] The CDF collaboration has reported similar measurements.[2] These analyses search for two independent modes that produce single top quarks: the s-channel process $q'\bar{q}{\rightarrow}tb$ with a predicted cross section $\sigma = 0.73 \pm 0.04$ pb;[3] and the t-channel process $q'g{\rightarrow}tqb$ with $\sigma = 1.70 \pm 0.19$ pb.[4] We use the notation "tb" to refer to both $t\bar{b}$ and the charge-conjugate process $\bar{t}b$, and "tqb" for both $tq\bar{b}$ and $\bar{t}\bar{q}b$. Events are identified by the presence of one isolated electron or muon and missing transverse momentum assumed to be from the decay of a W boson to a lepton and neutrino. The events must also contain two to four jets, with one or more having an associated muon to tag it as a possible b jet.

The principal difficulty in undertaking a search for single top quarks is that there are many other processes with similar topologies, but far higher cross sections. The single top quark processes represent a combined cross section of 2.4 pb, which corresponds to about one in 10^{10} interactions. After selecting interesting events with suitable triggers, the percentage of signal in e+jets or μ+jets decays is increased to 0.002%. Application of particle identification criteria and judicious selections to reject the backgrounds increases the combined percentage to 4%. This is the best that can be done using simple event-selection techniques and the modest amount of data currently available to DØ.

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Improving the signal selection and background rejection in the search for single top quark events is important, since observation of this complementary production mode would add significantly to the knowledge of the top quark obtained from studies of $t\bar{t}$ pairs.[5] For instance, the cross section for the electroweak production of top quarks determines the magnitude of the CKM matrix element V_{tb}.[6] Two avenues are being pursued to enhance the search for single top quark production. We expect to increase the amount of data by a factor of ≈ 20 in Tevatron Run 2. The quality of the information associated with each event will be improved significantly, owing to the addition of the Silicon Microstrip Tracker for reconstructing secondary vertices in b jets, and from improvements in electron and muon identification systems. Before these data become available, we can also enhance signal selection techniques with the use of neural networks, which will enable us to extend the search into events without a tagging muon.

A detailed understanding of the backgrounds in the single top quark channels can also be used to increase signal acceptance and background rejection, and efforts are being focused on areas of the analysis that can lead to significant improvements. In this paper, we discuss the backgrounds after imposition of sequentially tighter signal selections, and note where improvements of the analysis in Run 2 appear likely. Since the final state particles in single top quark events are the same as for associated Higgs boson production $q'\bar{q}\rightarrow WH$ with $H\rightarrow b\bar{b}$, understanding the backgrounds to single top quark production will also help in the investigation of this important process.

Table 1. Percentages of signal and background events predicted after the imposition of each set of criteria.

	tb	tqb	$t\bar{t}$	Wbb	$Wc\bar{c}$	Wjj	WW	WZ	QCD	Other
Electron Chan.										
Trigger	0.00050	0.0012	0.0083	0.0038	0.017	5.7	0.0094	0.0013	94	—
Baseline	0.20	0.34	5.3	0.65	0.72	3.1	0.43	0.13	89	—
Loose	0.75	1.3	11	3.8	4.4	17	2.2	0.73	59	—
Tight	1.4	2.1	8.7	6.3	6.8	25	3.4	1.2	45	—
Muon Channel										
Trigger	0.00093	0.0022	0.015	0.0055	0.023	7.4	0.020	0.0029	?	93
Baseline	0.15	0.27	4.0	1.3	1.3	3.9	1.2	0.25	5.7	82
Loose	1.0	2.0	15	3.8	3.8	8.6	3.6	0.60	8.0	54
Tight	1.6	2.6	9.0	5.3	5.3	4.8	5.7	1.3	8.0	56

Table 1 shows the percentages of events for the two signals and eight separate backgrounds that remain in the DØ Run 1 data after four stages of event selection: triggering (*Trigger*), particle identification (*Baseline*), obvious background rejection (*Loose*), and optimized signal selection (*Tight*). "$Wc\bar{c}$" refers to $Wc\bar{c}$+Wcs+$Ws\bar{s}$ events. "Wjj" includes events with only light jets ($j = u$, d, g), and so all the tagged jets in this sample are either mistagged or uninteresting (π or K decays). In the electron channel, "QCD" refers to multijet events where a jet is mistaken for an electron. In the muon channel, "QCD" refers to $b\bar{b}$ events where a nonisolated muon from a b decay is mistaken for an isolated muon. "Other" means multijet events with the isolated muon coming from either a coincident cosmic ray, a mistake in pattern recognition, or from a particle back-scattered off a beamline magnet into the spectrometer.

It is clear from Table 1 that, after trigger selection and implementation of particle identification, most of the electron-channel candidates correspond to multijet events with a jet mistaken as an electron. In the muon channel, a similar fraction of events have no true muon. After imposition of the tight criteria, the next-largest background in the electron channel comes from W+jets events with a fake muon tag.

Before other selections are applied to the single top quark signals, the triggers are 40% efficient in the electron channel and 60% in the muon channel. In Run 2, it may be possible to lower thresholds and include more objects in the trigger definitions, and thereby improve the efficiencies without increasing rates from background.

Baseline selections require at least one object in the event to pass the isolated electron or muon identification criteria, at least two jets, and at least one good tagging muon. Only 28% of electrons in the original Monte Carlo signal samples pass the electron ID requirements (60% after passing trigger thresholds). These criteria are tight in order to minimize the rate from jets that mimic electrons. Nevertheless, the sample is still dominated by multijet events. We find that 30% of the muons in the MC signal samples pass the isolated muon ID requirements (44% after trigger thresholds are passed). Contributions to these inefficiencies from geometrical acceptance will not change much in Run 2, but lowering the transverse momentum thresholds could significantly increase the efficiency.

The main difference between the loose selections in the two decay channels is the rather severe one used to reject cosmic-ray contamination in the muon channel. This has the additional effect of rejecting much of the W+jets background, although it also throws out 30% of the single top quark events that fail no other selection. If, despite the major detector improvements in Run 2, we observe a significant fraction of events with false isolated-muons, then more effort will have to go into either rejecting this background offline, or measuring it and including it in the background calculations.

To conclude, we have completed a search for single top quark production at DØ. The reader is referred to Ref. 1 for details on the triggers, the three sets of selections, and for specifics on particle identification. Limited statistics prevented the application of tighter selections for rejecting background because of the need to maximize the small signal acceptances. However, even under these circumstances, we found it relatively straightforward to reduce the $t\bar{t}$ background, but, because of the large cross sections, it was very difficult to reject W+jets events with false muon tags, and events with false electrons or false isolated muons dominate the background. These instrumental backgrounds may continue to limit sensitivities to similar signals in Run 2.

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